

DEPARTMENT OF THE ARMY
U. S. Army Corps of Engineers
Washington, DC 20314-1000

EM 1110-2-1201

CEEC-EH

Engineer Manual
No. 1110-2-1201

30 June 1987

Engineering and Design
RESERVOIR WATER QUALITY ANALYSIS

Table of Contents

	<u>Subject</u>	<u>Paragraph</u>	<u>Page</u>
CHAPTER 1	INTRODUCTION		
Section I.	General		
	Purpose	1-1	1-1
	Applicability	1-2	1-1
	References	1-3	1-1
	Background	1-4	1-1
Section II.	Water Quality Assessment in Water Quality Control Management		
	General	1-5	1-2
	Planning and Analysis	1-6	1-2
	Water Control Management	1-7	1-3
CHAPTER 2	WATER QUALITY PARAMETERS		
Section I.	Introduction		
	Definition of Water Quality	2-1	2-1
	Reservoir-Watershed Relationship	2-2	2-1
Section II.	Reservoir Description		
	Definition	2-3	2-1
	Comparison to Natural Lakes	2-4	2-1
	Classification of Reservoirs	2-5	2-2
Section III.	Reservoir Characteristics and Processes		
	General	2-6	2-6
	Physical Characteristics and Processes	2-7	2-6
	Chemical Characteristics of Reservoir Processes	2-8	2-26
	Biological Characteristics and Processes	2-9	2-33
Section IV.	Releases and Tailwaters		
	Releases	2-10	2-39
	Tailwaters	2-11	2-39
	Characteristics and Processes	2-12	2-40
CHAPTER 3	WATER QUALITY ASSESSMENT		
Section I.	Designing the Assessment Plan		
	Establishing Objectives	3-1	3-1

	<u>Subject</u>	<u>Paragraph</u>	<u>Page</u>
	Design Considerations	3-2	3-11
	Elements of Assessment	3-3	3-12
Section II.	Water Quality Assessment Program/ Study Categories		
	Preimpoundment Assessment	3-4	3-14
	Postimpoundment Assessment	3-5	3-18
	Operational Monitoring	3-6	3-21
	Modification of Operations	3-7	3-22
	Modification of Water Control Structures	3-8	3-23
	Specific Water Quality Problems	3-9	3-25
CHAPTER 4	WATER QUALITY ASSESSMENT TECHNIQUES		
Section I.	Scope	4-1	4-1
	Screening Techniques		
	General	4-2	4-1
	Information Search	4-3	4-1
	Project Characteristics and Calculations	4-4	4-2
	Site-Specific Water Quality Data	4-5	4-4
Section II.	Diagnostic Techniques		
	General	4-6	4-4
	Field Investigations	4-7	4-4
	Laboratory Studies	4-8	4-8
	Statistical Techniques	4-9	4-11
	Water Quality Indices	4-10	4-12
	Remote Sensing	4-11	4-12
Section III.	Predictive Techniques		
	General	4-12	4-13
	Regression Analysis	4-13	4-13
	Comparative Analysis	4-14	4-14
	Modeling	4-15	4-14
	Nutrient Loading Models	4-16	4-15
	Numerical Simulation Models	4-17	4-18
	Physical Models	4-18	4-29
CHAPTER 5	WATER QUALITY DATA COLLECTION AND ANALYSIS		
Section I.	Introduction		
	Purpose	5-1	5-1
	Overview	5-2	5-1
Section II.	Field Data Collection		
	Principles	5-3	5-2
	Sampling Designs	5-4	5-3
	Field Sampling and Analysis	5-5	5-8
	Laboratory Analysis	5-6	5-19

30 Jun 87

	<u>Subject</u>	<u>Paragraph</u>	<u>Page</u>
Section III.	Database Management		
	Database Management Systems	5-7	5-19
	Selection Criteria	5-8	5-22
Section IV.	Data Presentation		
	Methods	5-9	5-22
	Summary Tables	5-10	5-22
	Graphic Displays	5-11	5-23
	Quality Assurance	5-12	5-26
	Statistical Analysis	5-13	5-26
APPENDIX A	REFERENCES		
	Department of the Army, Corps of Engineers		A-1
	Department of the Army, Corps of Engineers, Waterways Experiment Station		A-1
	Other Government Publications		A-3
	Nongovernment Publications		A-5
APPENDIX B	BIBLIOGRAPHY		B-1
APPENDIX C	SAMPLE DESIGN CALCULATIONS: DEVELOPMENT OF DECISION MATRIX (TABLE 5-1)		C-1
APPENDIX D	ORDER OF MAGNITUDE ESTIMATES		
	Purpose	D-1	D-1
	Morphometric and Hydrologic Characteristics	D-2	D-1
	Physical Relationships	D-3	D-3
	Chemical Relationships	D-4	D-4
GLOSSARY			GLOSSARY-1

	<u>List of Tables</u>	<u>Page</u>
2-1	Selected Trophic Indicators and Their Response to Increased Eutrophication	2-5
2-2	Physical, Chemical, Morphometric, and Hydrologic Relationships	2-7
2-3	Nutrient Demand:Supply Ratios During Nonproductive and Productive Seasons	2-29

<u>List of Tables</u>		<u>Page</u>
3-1	Water Quality Concerns and Possible Contributing Factors	3-10
4-1	Summary of Existing Instream Flow Assessment Methods	4-9
4-2	Summary of Simulation Model Attributes	4-22
5-1	Example of a Sampling Matrix to Optimize Sample Numbers, Precision, and Cost	5-7
5-2	Example of Sampling Intervals Corresponding with Hydrologic and Limnological Periods	5-13
5-3	Typical Water Quality Variables Measured in Reservoirs and the Sample Handling and Preservation Requirements	5-14
5-4	Example of Description Statistics That Can Be Applied to Water Quality Data	5-24
5-5	Summary of Parametric Statistical Tests	5-32
5-6	Summary of Nonparametric Statistical Tests	5-35
<u>List of Figures</u>		<u>Page</u>
2-1	Longitudinal patterns in reservoir water quality	2-12
2-2	Vertical zonation resulting from thermal stratification	2-13
2-3	Illustration of bottom withdrawal structure, spillway, and stilling basin	2-14
2-4	Example of a surface withdrawal structure	2-15
2-5	Dual wet well multilevel withdrawal structure	2-16
2-6	Water density as a function of temperature	2-18
2-7	Recurring annual stratification pattern for temperate reservoir	2-20
2-8	Density inflows to reservoirs	2-21

<u>List of Figures</u>		<u>Page</u>
2-9	Internal mixing processes in reservoirs	2-22
2-10	Influence of penetrative convective mixing on deepening the mixing layer	2-23
2-11	Important hydrodynamic features of pumped-storage reservoirs subject to jetting inflows	2-25
2-12	Characteristic metalimnetic DO minimum	2-27
2-13	Orthograde and clinograde vertical DO distribution	2-28
2-14	Seasonal phosphorus flux under aerobic and anaerobic conditions	2-32
2-15	Seasonal patterns of phytoplankton succession	2-35
2-16	Lateral distribution of macrophytes in littoral zone	2-36
2-17	Generalized reservoir ecosystem indicating physical, chemical, and biological interactions including higher trophic levels	2-37
2-18	Potential effects and interactions of modified flow regime on downstream biota	2-41
2-19	Schematic of a hydropower facility	2-44
2-20	POC concentrations and transport during hydropower generation cycle	2-46
3-1	Contributing factors and potential consequences of algae blooms	3-3
3-2	Contributing factors and potential consequences of aquatic weed infestations	3-4
3-3	Contributing factors and potential consequences of high bacterial counts	3-5
3-4	Contributing factors and potential consequences of altered release temperatures	3-6
3-5	Contributing factors and potential consequences of release DO concentrations	3-7

	List of Figures	Page
3-6	Contributing factors and potential consequences of gas supersaturation	3-8
3-7	Contributing factors and potential consequences of fish stress on both the reservoir and tailwater fishery	3-9
3-8	Project characteristics known prior to beginning a water quality study	3-15
3-9	Typical water quality factors to be assessed in reservoir water quality studies	3-16
4-1	Selected information retrieval services	4-3
4-2	Control pathways in a typical nutrient loading model	4-16
4-3	Comparison of model dimensions	4-19
4-4	Typical water quality model constituents and pathways	4-21
4-5	Model representation for conservation of mass	4-24
4-6	Statistical comparison of computer simulation results for two management alternatives	4-26
5-1	Potential bias in sampling program using a fixed interval (e.g., 30-day) sampling period	5-11
5-2	Example data plots	5-25
5-3	Comparison of graphic display methods	5-27
5-4	Example scatter diagrams	5-28